Trapped Vortex Combustor Development for Military Aircraft

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Tomorrow's military aircraft will require improved durability leading to life-cycle cost reductions and reduced emission levels while demanding higher performance. A combustor concept that is being developed with these goals in mind is the Trapped Vortex Combustor (TVC). Early testing at AFRL showed that the TVC has the potential to deliver exceptional performance and low emissions. Based on its potential for high-power performance, the TVC was chosen as the ATEGG Phase 3 combustor. Although the ATEGG Phase 3 program has stopped, development of the TVC continues through a joint technology development effort between GE Aircraft Engines, the Navy, and ESTCP.

This development program will take the TVC from the laboratory test stage through design and fabrication of engine worthy combustor hardware. Once the hardware fabrication is complete, the current program provides for one full annular test with an option for a second full annular test. The schedule in **Figure-1** shows the TVC development timeline with completed items in gray. The first full annular design of a TVC completed testing in April 2007. Ultimate plans are for the TVC to be transitioned into a demonstration engine to achieve a Technology Readiness Level (TRL) of 6.

The TVC has been designed to fit within an existing engine architecture, and all TVC goals and objectives are benchmarked against the production combustor. Specific goals for the TVC, relative to the production combustor include:

- 50% reduction in high-power Nitrogen Oxides (NOx)
- 60% reduction in low-power Carbon Monoxide (CO)
- 80% reduction in low-power HydroCarbons (HC)

Objectives are in place to improve altitude relight, lean-blow-out, and durability while maintaining cost, weight and combustor exit temperature profile.

What makes the Trapped Vortex Combustor so unique is the use of driven cavities incorporated into the combustor liners. The concept being developed differs from the ATEGG Phase 3 TVC in that it uses a rich-quench-lean design approach. All of the fuel is introduced into the cavities where it evaporates and mixes with a portion of the total combustor air, partially burns, and eventually leaves the cavities. Main air chutes through the dome are used to trap the vortices in the cavities increasing the mixing time, and provide additional air to mix with the partially burned gases to complete combustion and quench NOx formation prior to reaching the exhaust plane. **Figure-2** provides a schematic illustration of this process.

Report Documentation Page			*Form Approved* *OMB No. 0704-0188*
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1. REPORT DATE **2008**	2. REPORT TYPE		3. DATES COVERED **00-00-2008 to 00-00-2008**
4. TITLE AND SUBTITLE **Trapped Vortex Combustor Development for Military Aircraft**			5a. CONTRACT NUMBER
			5b. GRANT NUMBER
			5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)			5d. PROJECT NUMBER
			5e. TASK NUMBER
			5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Air Systems Command,Propulsion and Power Division,22195 Elmer Road, Unit 4,Patuxent River,MD,20657**			8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)			10. SPONSOR/MONITOR'S ACRONYM(S)
			11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**			
13. SUPPLEMENTARY NOTES			
14. ABSTRACT			
15. SUBJECT TERMS			

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**6**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

To verify progress towards the program goals, the TVC program has accomplished tests using several different designs in a 5-cup combustor sector and a Full Annular Rig (FAR) combustor shown in **Figure-3**. Based on the test results so far, the TVC continues to move towards the goal emission reductions; however, additional work is still needed to meet these goals. The FAR test, completed in April 2007, yielded a 42% reduction in high power NOx compared to the production engine. **Figure-4** displays these results plotted against severity parameter, a nondimensional parameter that provides a linear NOx relation allowing comparisons between combustors at different operating conditions. The FAR testing has been done at full engine conditions (i.e., pressures, temperature, and air-flows). At ground idle, the TVC has demonstrated a 17% reduction in hydrocarbon emissions during the FAR testing, shown in **Figure-5**. The poorer than expected low power performance compared to the earlier sector testing was partly a consequence of poor fuel atomization during the test. The causes of this are well understood and will be corrected for the next FAR test scheduled for late 2007 or early 2008. All other performance objectives such as lean-blow-out and altitude relight have been demonstrated with margin compared to the production combustor performance levels. An additional benefit to the TVC, which was demonstrated during the 5-cup rig test, was an improvement in low-power efficiency. This translates into a reduced fuel burn at engine ground idle conditions.

The trapped vortex combustor design used in the first FAR test is shown in **Figure-6** along with the proposed surrounding engine hardware. With this first combustor FAR test having shown progress towards meeting the emissions goals, the design and fabrication of the second FAR hardware has been initiated. **Figure-6** shows a proposed outer case design and combustor inlet diffuser design that will be retrofittable into an engine as a new Combustor-Diffuser-Nozzle (CDN) module. One aspect of the TVC that cannot be exploited in this retrofittable application is the potential for significantly shortening the combustion system length. With the design shown in **Figure-6**, there is a potential for taking over 1” out of the CDN length even after length has been added to the proposed diffuser to increase the area ratio and potentially improve the pressure loss and distribution performance.

Being a unique design, the TVC has introduced some significant mechanical design challenges. Objectives for the TVC state that there should be no compromise for durability, weight or cost. Mechanical analyses focusing on durability are continuing as the design progresses. With the recently completed full annular rig test the thermal and mechanical models will be validated using the data from the heavily instrumented combustor. Recent design changes have brought the TVC weight to within 13% of the technical requirement imposed on the existing engine. Cost projections show that future TVC production hardware will meet the cost goals.

Several years of combustor component testing have indicated that the TVC design has the potential to deliver high performance geared towards an advanced military engine application while also delivering low emissions, exceptional operability, and a short combustor length. The TVC program is continuing to develop and validate this combustor concept in the second full annular test. At the conclusion of this component

test the engine quality hardware will be transitioned into a demonstration engine when one becomes available to validate this potential, and lead the way to introduce TVC technology into future advanced military engine products.

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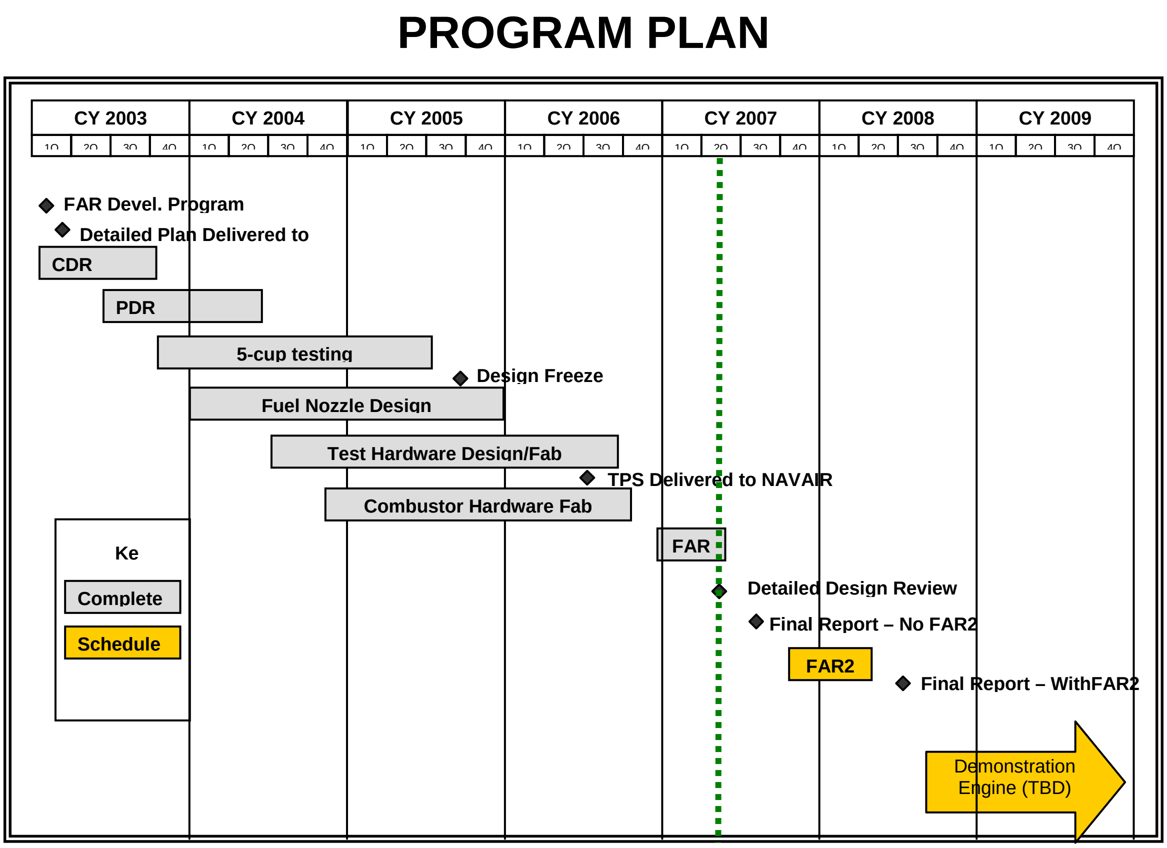

Figure-1: Trapped Vortex Combustor (TVC) Program Plan

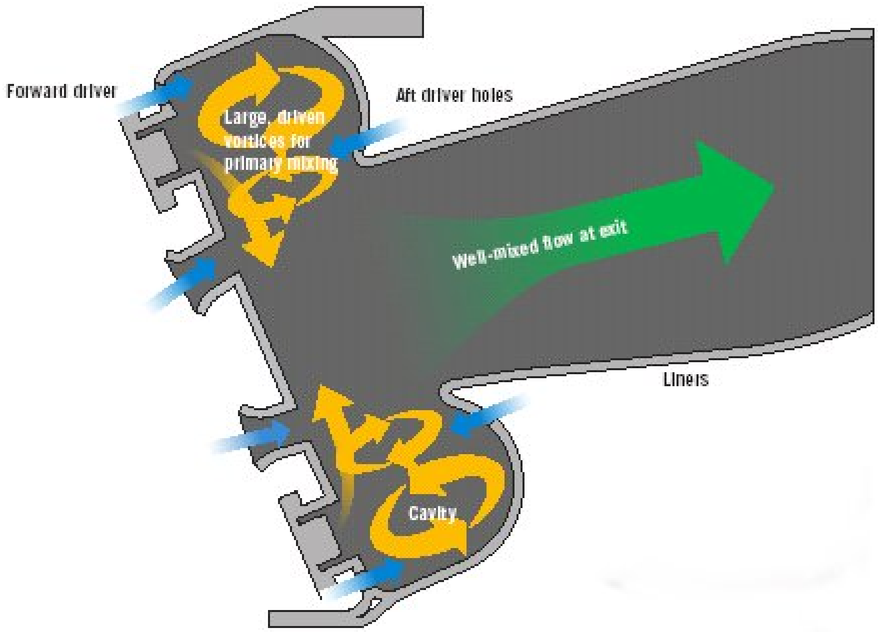

Figure-2: Trapped Vortex Combustor (TVC) Air Flows and Cross Section

Figure-3: TVC Full Annular Rig (FAR) Hardware with Instrumentation

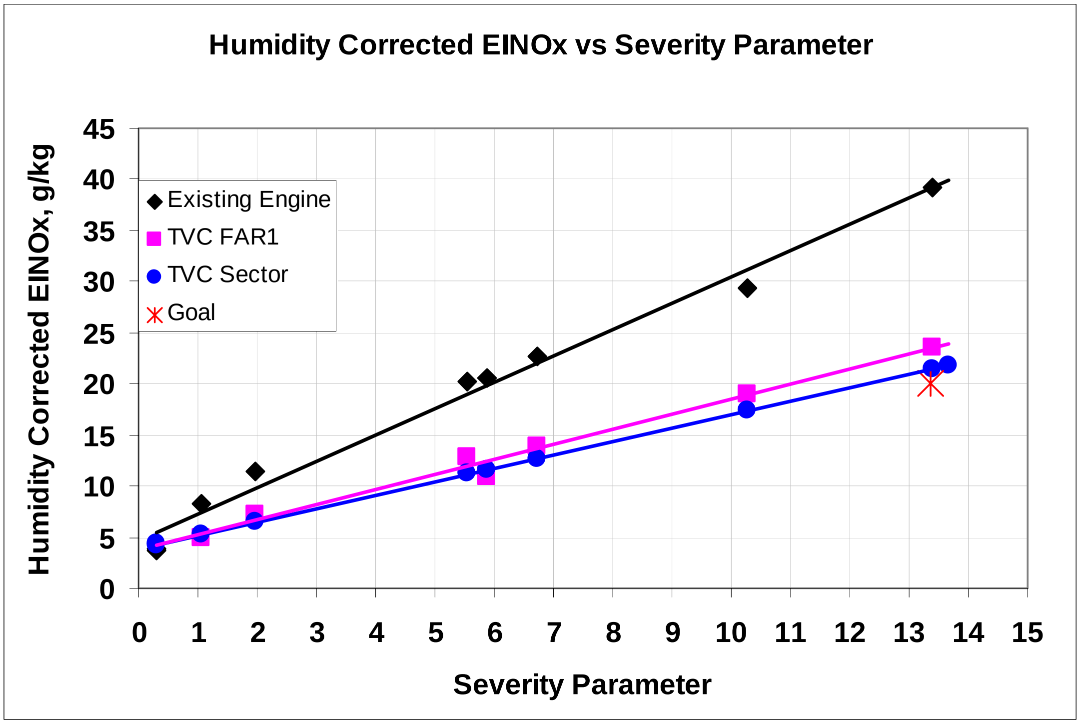

Figure-4: Emissions Index (EI) NOx Reductions Relative to Existing Engine

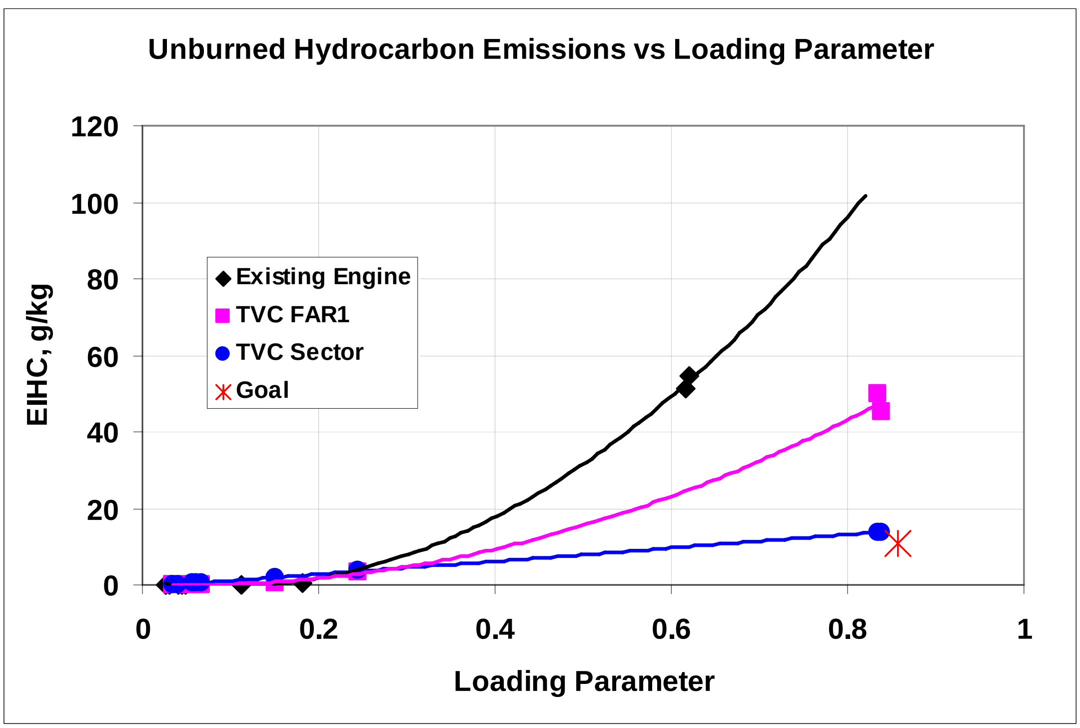

Figure-5: Emissions Index (EI) HC Reductions Relative to Existing Engine

Figure-6: Proposed TVC Combustor-Diffuser-Nozzle (CDN) module